

Exponent 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 90.23 percent

Figure 9

Receive
 Pattern



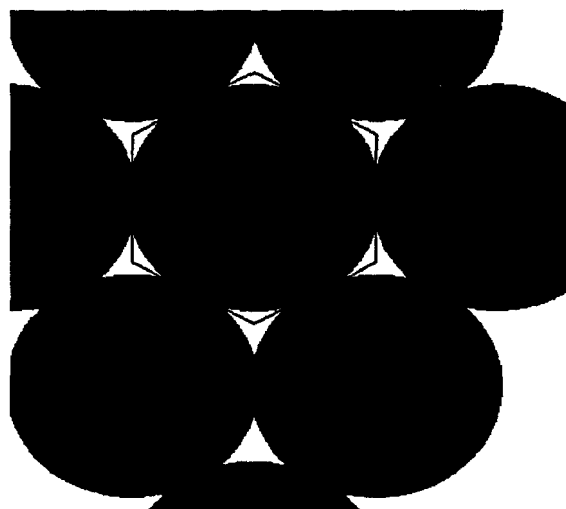
Transmit
 Pattern



Recv Alt : 1500 ft
 Xmtr Alt : 500 ft
 Radio H : 86 mi

0 100

Scale in miles



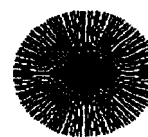
Exponent 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 95.33 percent

Figure 10

Receive
 Pattern



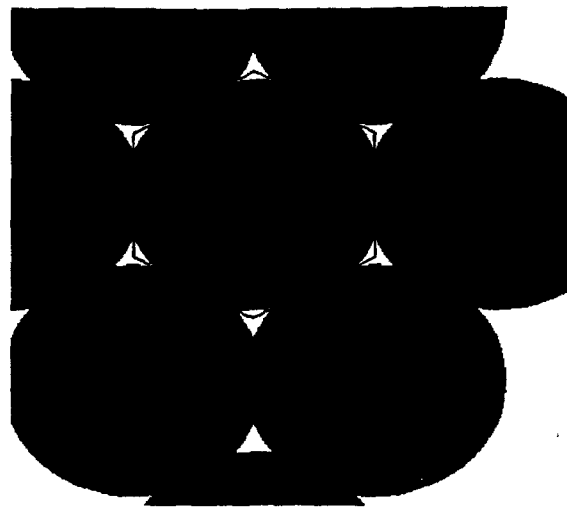
Transmit
 Pattern



Recv Alt : 1700 ft
 Xmtr Alt : 500 ft
 Radio H : 90 mi

0 100

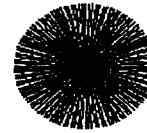
Scale in miles



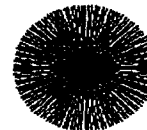
Exponent 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 98.06 percent

Figure 11

Receive
 Pattern



Transmit
 Pattern



Recv Alt : 1900 ft
 Xmtr Alt : 500 ft
 Radio H : 93 mi

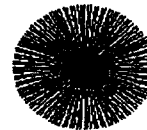
0 100
 Scale in miles



Exponent 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 100.00 percent

Figure 12

Receive
 Pattern

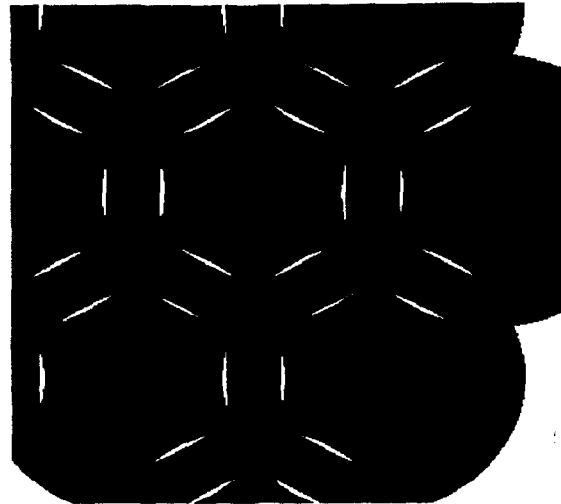


Transmit
 Pattern



Recv Alt : 2500 ft
 Xmtr Alt : 500 ft
 Radio H : 102 mi

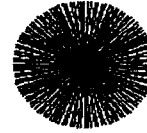
0 100
 Scale in miles



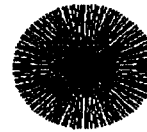
Exponent 2
Threshold: 13.0 dB
Antenna Pattern: 360 degree beam
Coverage: 97.92 percent

Figure 13

Receive
Pattern

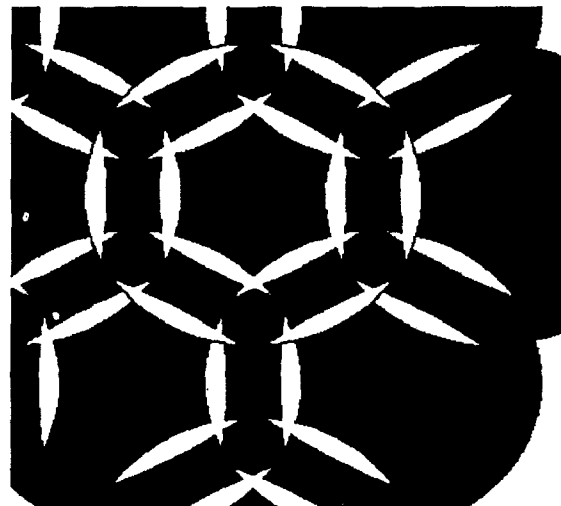


Transmit
Pattern



Rcvr Alt : 3000 ft
Xmtr Alt : 500 ft
Radio H : 109 mi

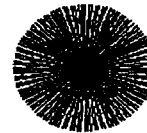
0 100
Scale in miles



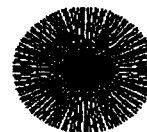
Exponent 2
Threshold: 13.0 dB
Antenna Pattern: 360 degree beam
Coverage: 77.57 percent

Figure 14

Receive
Pattern

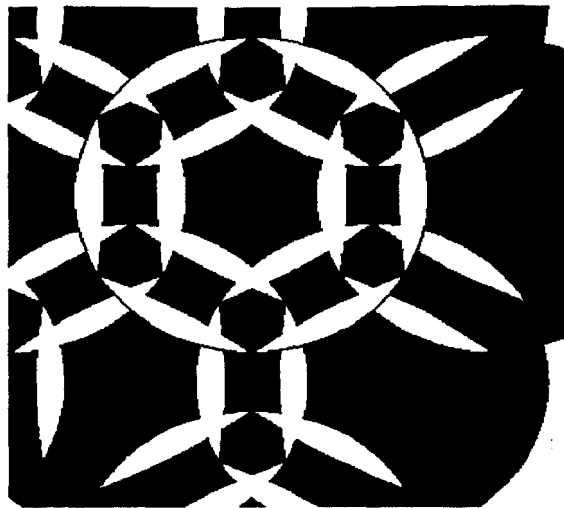


Transmit
Pattern



Rcvr Alt : 4000 ft
Xmtr Alt : 500 ft
Radio H : 121 mi

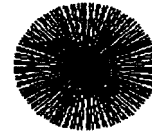
0 100
Scale in miles



Exponent: 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 68.10 percent

Figure 15

Receive
 Pattern

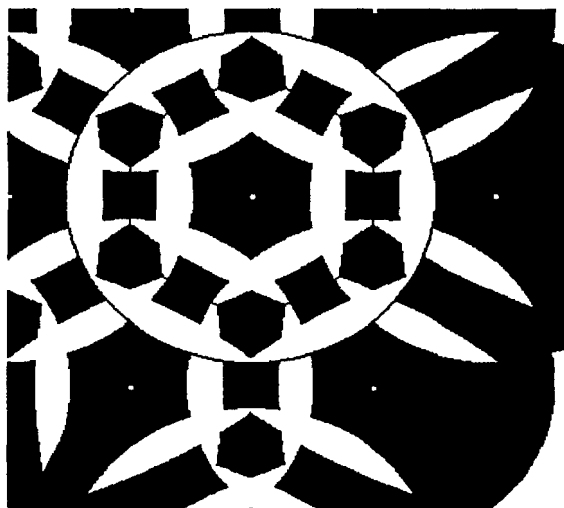


Transmit
 Pattern



Recv Alt : 4500 ft
 Xmtr Alt : 500 ft
 Radio H : 126 mi

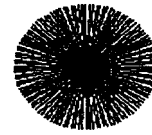
0 100
 Scale in miles



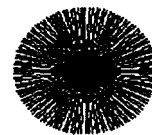
Exponent: 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 54.88 percent

Figure 16

Receive
 Pattern

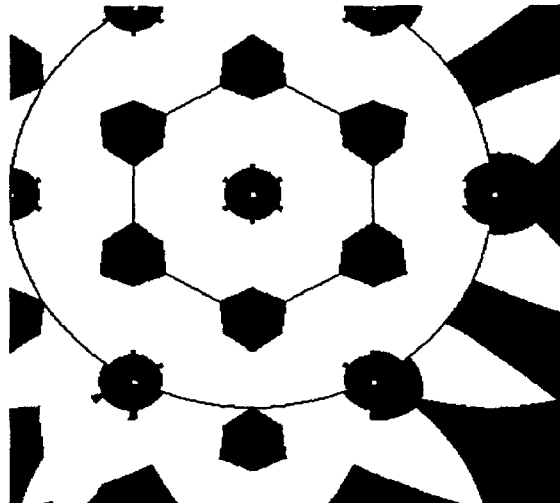


Transmit
 Pattern



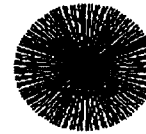
Recv Alt : 5000 ft
 Xmtr Alt : 500 ft
 Radio H : 132 mi

0 100
 Scale in miles

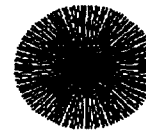


Exponent: 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 19.20 percent
 Figure 17

Receive
 Pattern

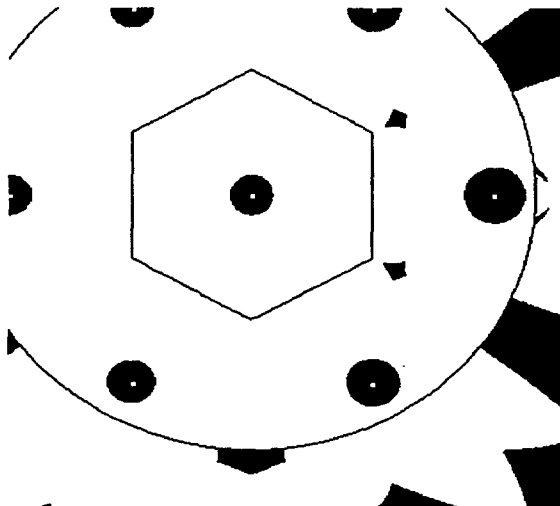


Transmit
 Pattern



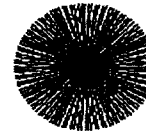
Rcvr Alt : 10000 ft
 Xmtr Alt : 500 ft
 Radio H : 173 mi

0 100
 Scale in miles

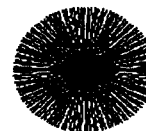


Exponent: 2
 Threshold: 13.0 dB
 Antenna Pattern: 360 degree beam
 Coverage: 2.99 percent
 Figure 18

Receive
 Pattern



Transmit
 Pattern



Rcvr Alt : 15000 ft
 Xmtr Alt : 500 ft
 Radio H : 205 mi

0 100
 Scale in miles

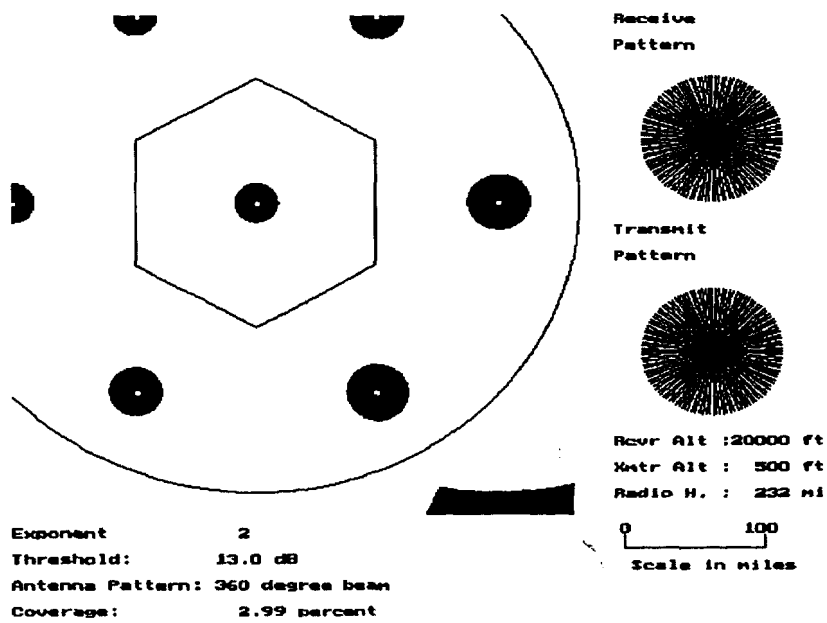


Figure 19

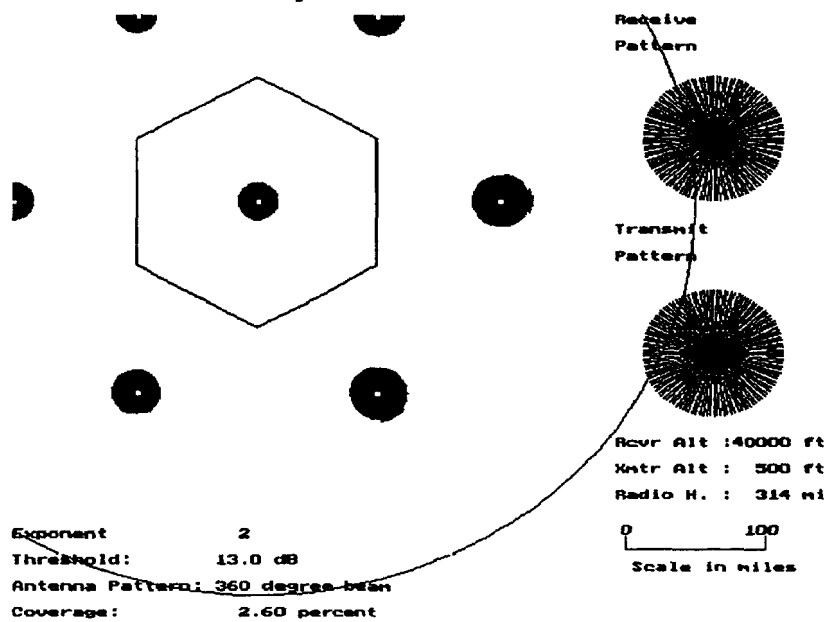


Figure 20

These predicted interference effects flow from the use of the free-space propagation model. If we assumed a higher rate of signal attenuation (as is the case for terrestrial

paging systems), we would see far less interference and far greater coverage. Note also that in many of the potential terrestrial interference conditions, the condition for successful simulcasting is met.

Figure 21 displays the coverage that would be provided to aircraft flying at 20,000 feet from the same array of stations as in Figure 19, but assuming an inverse fourth-power propagation law. As you can see the coverage is substantially better.

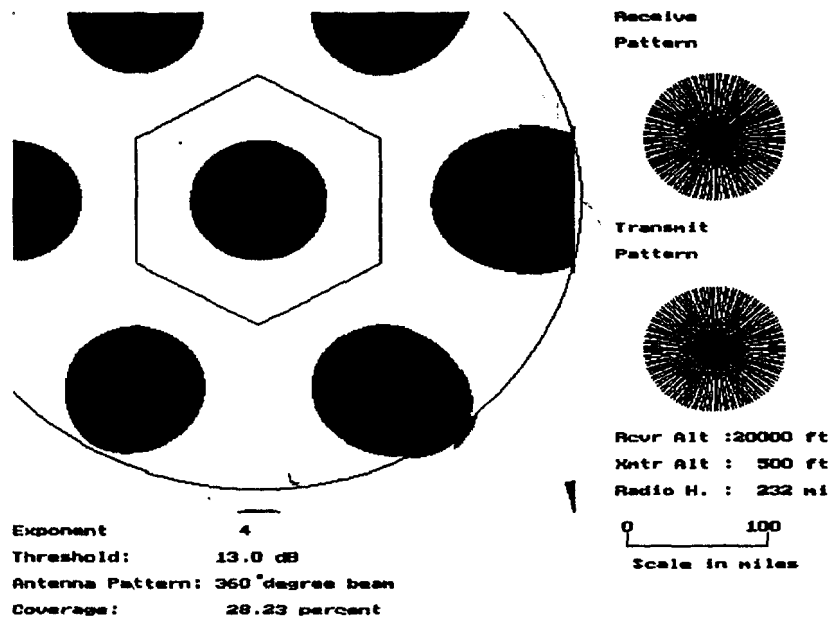
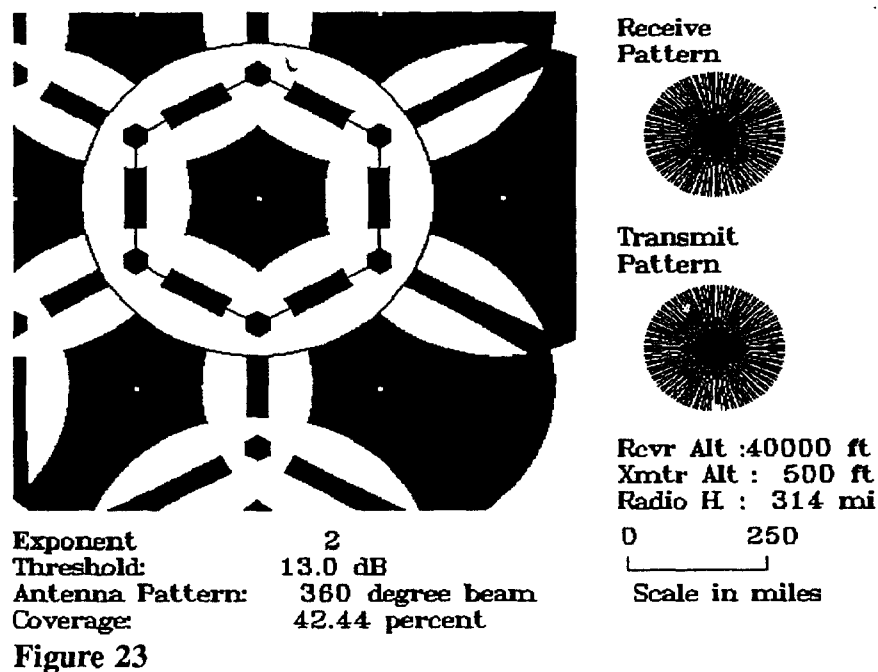
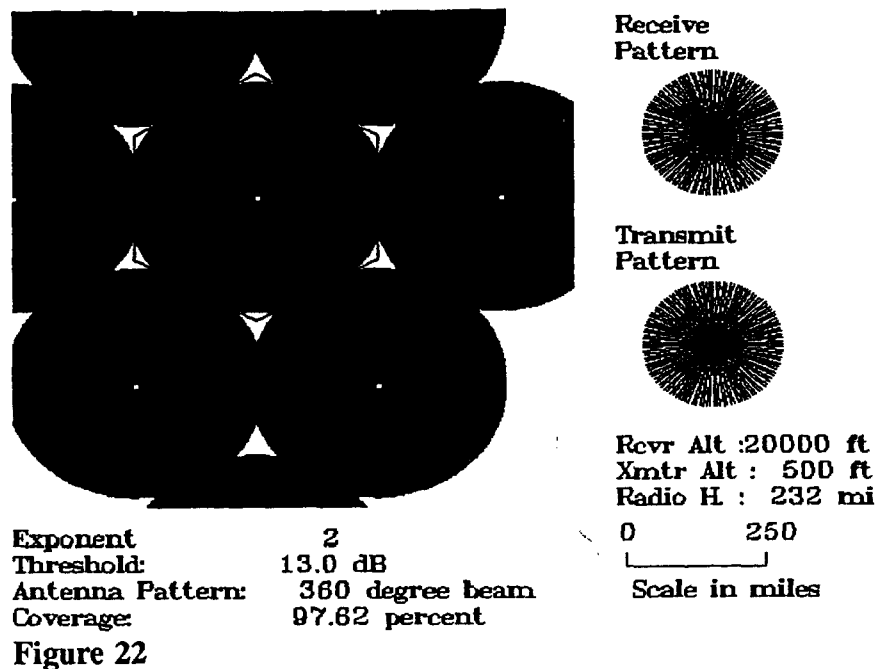


Figure 21

The figures below show the same trade-off between coverage at higher and lower aircraft altitudes. Figure 22 shows the coverage that would be obtained at 20,000 feet for this specific transmitter spacing (which is almost optimal for 20,000 feet). Figure 23 exhibits the coverage that the same array of transmitters would provide to aircraft at 40,000 feet.



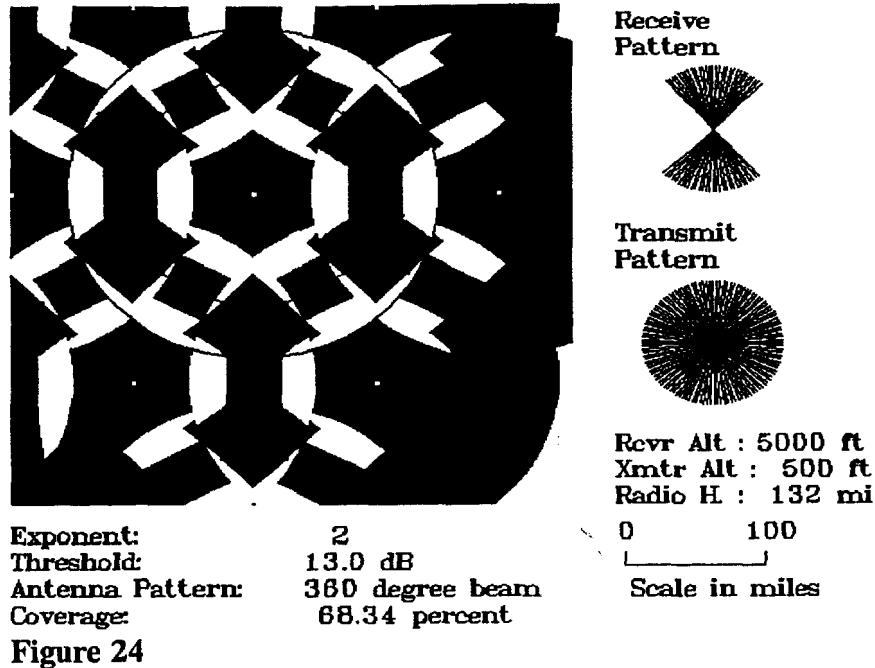
All of the above analyses have assumed that the receiver was equally sensitive in all directions. But, theory and experience indicate that pagers in aircraft have directional reception patterns. What effect will this have on coverage? We can do a pair of quick mental experiments that indicate that such directionality should increase coverage.

First, consider the case of a steerable high-gain directional antenna at the pager. This antenna could be pointed at one of the paging transmitters above the horizon. The antenna gain would be sufficient to eliminate interference from the other transmitters. In this circumstance, the directional antenna improves coverage by helping reject interference. However, the assumption that the directional antenna could be pointed to the desired transmitter is unrealistic.

Second, consider the case of a high-gain antenna pointing at random at a line of transmitters. If the beamwidth of the antenna is matched to the separation of the antennas, it will frequently "see" one antenna and will never see two. Coverage would be quite good.

We can modify our model to take into account receiving system directivity. In particular, let us assume that the receiver pattern forms a bow-tie-like pattern with two 90 degree fans of low relative attenuation off to the sides of the aircraft and 20 dB greater attenuation towards the front and back of the aircraft.

Figure 24 shows the coverage that would be expected from an array of omni-directional transmitters to directionalized receiving systems for an aircraft at 5,000 feet. This corresponds to the case studied earlier with omni patterns in Figure 16. The assumed receiving pattern is shown in the figure. A nominal gain of 0 dB is applied to all signals coming in on two fan-shaped beams. Signals from all other directions have a relative gain of -20 dB. Notice that coverage has increased from 55 percent to 68 percent. At this altitude (and with the assumed transmitter sites), directionality significantly improves system performance.



Notice that coverage improves when we assume the use of directional antennas. Notice also that, when the aircraft is sufficiently high to see several transmitters, coverage is still relatively low.

One approach to improving coverage is to stagger the transmissions in each cell. The analysis of such patterns is quite similar to the analysis of cellular reuse patterns in cellular radio. The biggest difference between this problem and the cellular problem is the effect of altitude. Wider separation of stations results in a greater unserved volume at lower altitudes. For example, if we were to stagger the transmissions in a seven-cell pattern, the stations could be arranged to provide essentially total coverage for a very large volume of air space. If transmitters were set up on a hexagonal array, they could provide coverage to essentially all aircraft at altitudes between 1,500 feet and 15,000 feet and to many aircraft above 15,000 feet.

The major problem with a seven-fold staggered transmission pattern is that it reduces capacity by the same amount. This approach might be quite useful in the early operation of such a system if it could be shown to reduce operational costs.

Another approach to reuse is to consider transmitters located in the center of a hexagonal array as before, but to assume that they use directional antennas to illuminate sectors at a time. For example, with an 180 degree fan, two transmissions would be required (one to the "north" and one to the "south"). Figure 25 through Figure 28 illustrate the use of some of these directional illumination patterns. In looking at these figures, the reader must take into account that the coverage in each cell would be the sum of the coverage from transmissions in multiple sectors and that we are looking only

at the effects of a transmission in a single direction. Notice that, as we narrow the beamwidth, high-altitude coverage improves substantially.

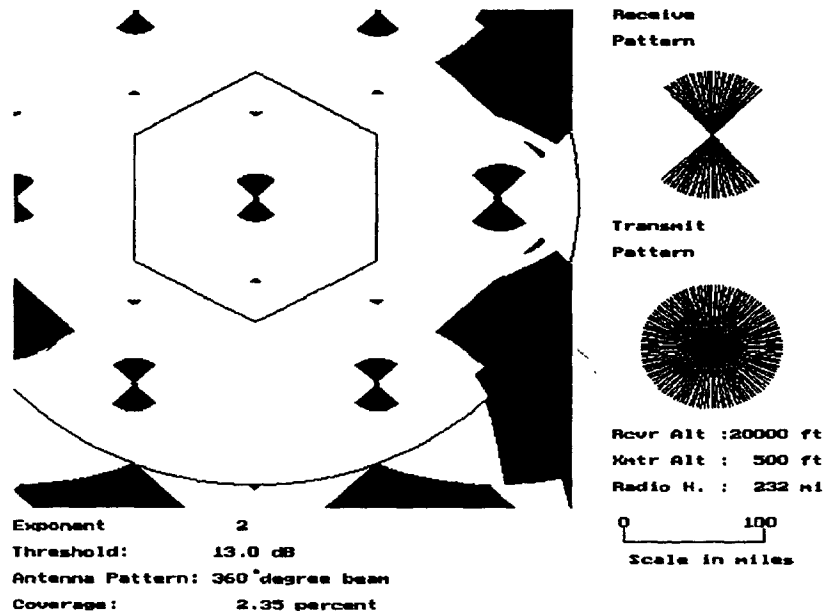


Figure 25

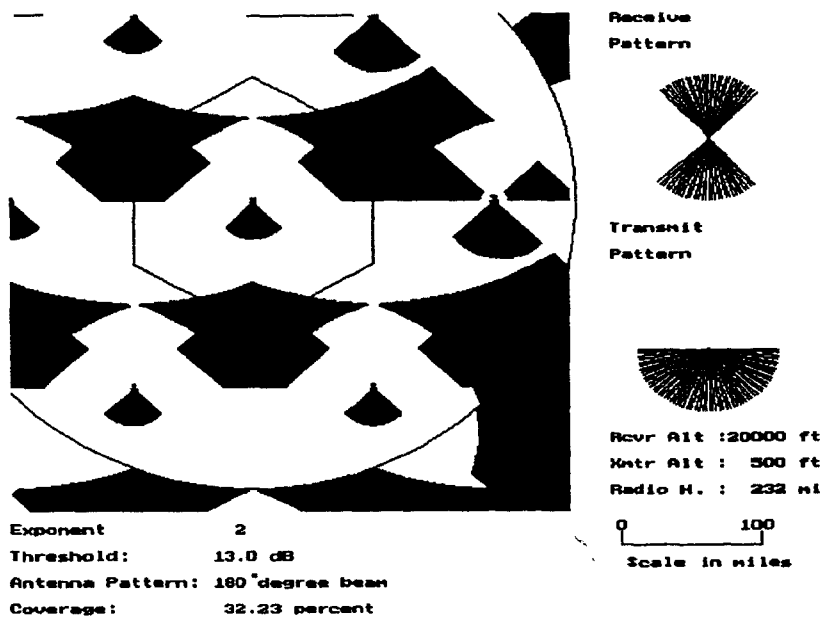


Figure 26

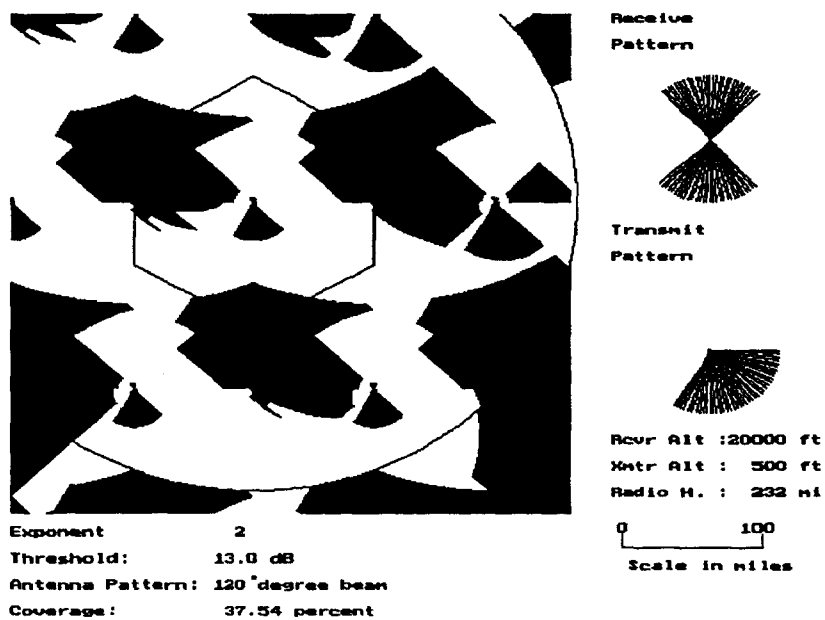


Figure 27

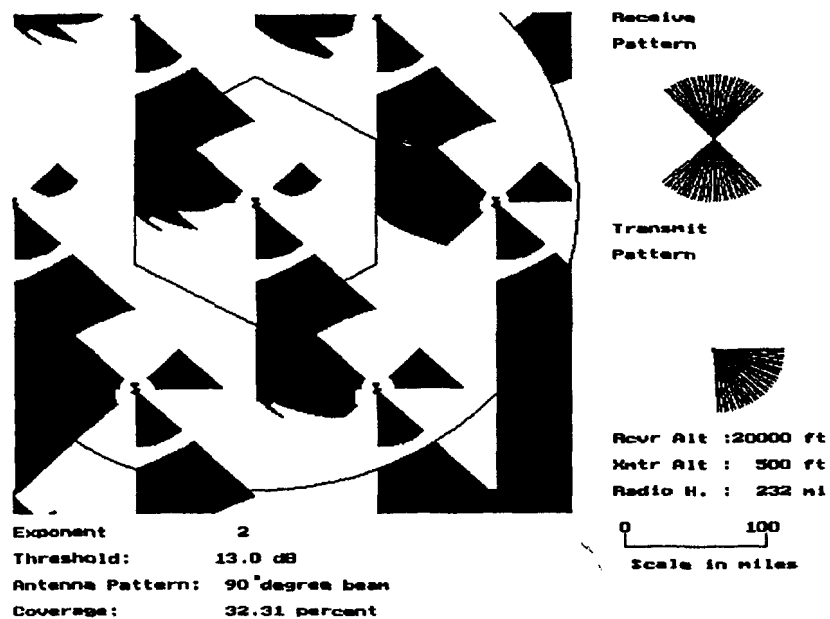


Figure 28

The following figures illustrate the effect of making the receiving system more directional. This might be accomplished in cooperation with the airlines. Windows on one side of the aircraft could be coated with a conductive mesh, reducing radio wave penetration on that side of the aircraft. Figure 29 through Figure 32 display the results of an analysis of such a configuration with different combinations of transmit antenna pattern and altitude.

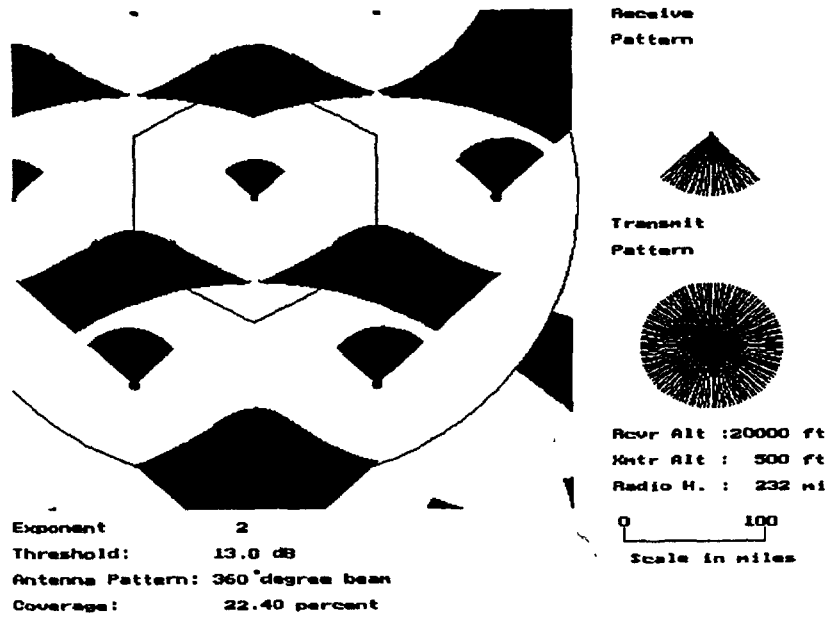


Figure 29

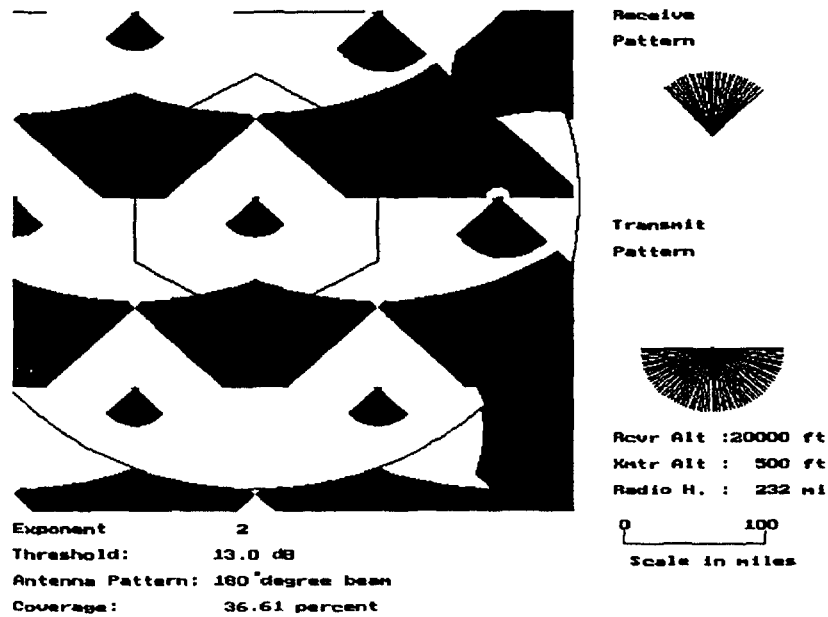


Figure 30

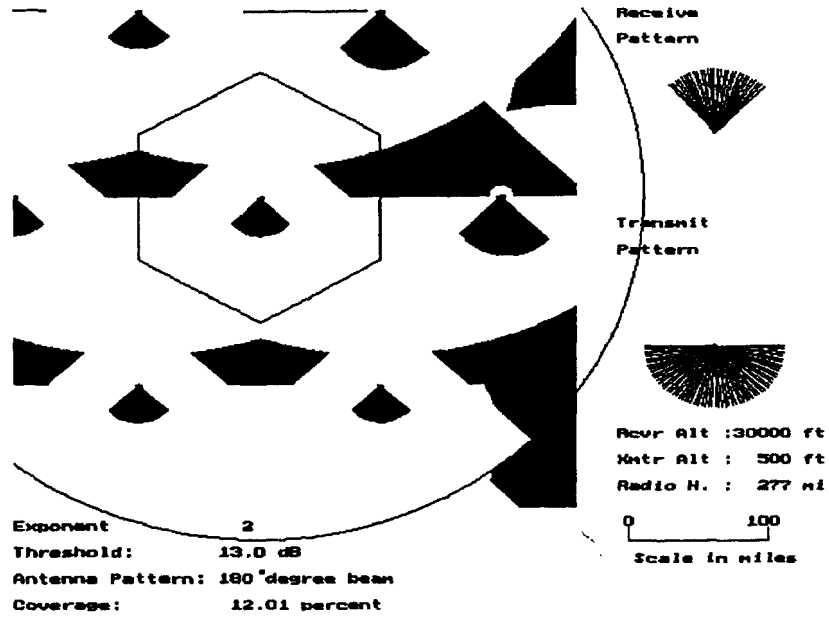


Figure 31

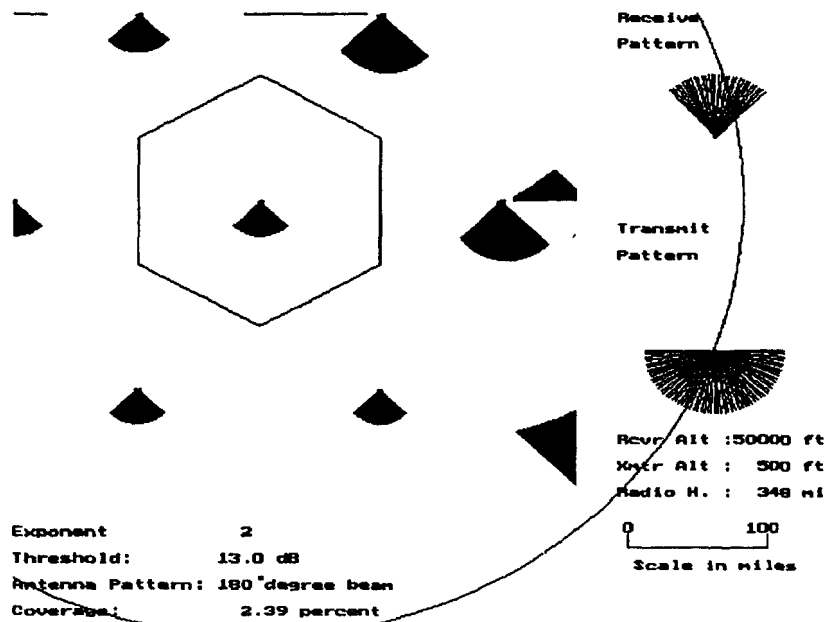


Figure 32

POLICY CONCLUSIONS

The foregoing discussion shows the requirement for spectrum coordination over a very wide area. The radio horizon for an aircraft at 40,000 feet is almost 300 miles. Thus, an aircraft at this altitude can receive signals from transmitters located in an area of about one-quarter million square miles. Yet the area of the continental U.S.⁷ is only about three million square miles. Given the need for coordination of transmitters that may simultaneously illuminate aircraft, it is clear that dividing a nationwide paging band among multiple licensees would lead to substantial practical problems in day to day frequency coordination among licensees. This is a different argument, based on the problems of spectrum management, from the argument that the nature of the market (air travelers may be anywhere in the nation) requires a nationwide service. This is a separate and different point. The technical characteristics of the service require coordination of the operation of transmitters over vast distances—distances equal to a significant fraction of the length or breadth of the continental U.S.

The same considerations also lead to a need to coordinate use with Canada and Mexico. Ideally, the frequencies of interest would be used for a similar GAP service in those countries. Alternatively, a non-conflicting use could be found for those frequencies. Note that non-compatible systems operating along both borders could substantially reduce the area (volume) served by such a system. Montreal is about 220 miles from Boston (radio horizon at 24,000 feet) and Los Angeles is less than 180 miles from Tijuana (radio horizon at 16,000 feet).

It should also be clear that substantial technical work needs to be done in order to provide the most spectrum-efficient and cost-effective GAP service. In particular, strategies for providing high-altitude coverage while maintaining good spectrum efficiency are necessary.

FURTHER TECHNICAL ISSUES

A substantial technical analysis needs to be done. Among the issues where additional study would appear to be helpful are:

- System interference issues;
- Characterization of pager operation within aircraft;
- Pager susceptibility to interference from simulcast pages. This analysis should be sufficient to understand the required signal-to-noise ratio for interfering signals from transmitters above the horizon at a mix of distances from 30 to 200 or more miles;
- Techniques for making aircraft more hospitable components in receiving systems. One such technique might be to cover windows on one side of the

⁷ The total area of the U.S. is 3,618,770. The area of Alaska is 591,004. The area of U.S. excluding Alaska is 3,027,776 square miles. *Statistical Abstract of the United States*, 1990, p. 195.

aircraft with a conductive coating. This would restrict paging signal penetration to windows on the other side of the aircraft—making the receiving system more directional. Another technique would be to put repeaters inside the aircraft and mount an external antenna or antenna system. A 10 mW transmitter at 30 meters provides a signal as strong as a 1000 W transmitter at six miles (without any allowance for aircraft penetration). Such repeaters could be designed to operate only when signal strength is sufficiently low so that the external signal would not interfere with the repeated signal inside the aircraft.

RELATED MARKETING ISSUES

There is a trade-off between low-altitude coverage and high-altitude coverage. By separating stations, interference at higher altitudes can be reduced, but at the expense of creating low altitude regions where coverage is poor. Such regions might be filled in through the use of low-power transmission (say, one or 10 W) or the holes in coverage might be accepted.

This problem should be thought through carefully from a marketing point of view. A large portion of air travel consists of shorter trips (e.g., Washington to Philadelphia or Dallas to Houston) where only a small portion of the flight time is spent above 10,000 feet. In contrast, the majority of the time on longer transcontinental flights is spent at higher altitudes. It may be the case that consumers who are frequently on these longer trips make up a significant portion of the GAP service market. If so, the GAP system should be designed to serve them well.

A system that has holes in its coverage may gain a bad reputation and find sales suffering significantly. A better understanding of the needs of potential customers would assist in designing a practical system. In particular, how should a system operator trade-off low-altitude coverage, high-altitude coverage and system cost?

CERTIFICATE OF SERVICE

I, Tana C. Maples, hereby certify that on this 16th day of June, 1992, I caused copies of the foregoing REPLY COMMENTS OF PACTEL PAGING to be sent by U.S. first class mail, postage prepaid, or by hand-delivery as specified, to the following:

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